

The influence of opening windows and doors on the natural ventilation rate of a residential building

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SCIENCE

Background

The “green building movement” is often associated with a recommendation to use natural ventilation when it does not decrease the indoor air quality (IAQ) of the ventilated space in an effort to reduce the need for mechanical ventilation and associated energy use.

To reduce building energy use on a broad scale, new buildings and retrofits often result in tighter buildings than those in the existing building stock. If no mechanical ventilation exists, as is most often the case in residential properties, other forms of ventilation are needed to make up for the reduced infiltration from natural building processes if IAQ is to be maintained.

The opening of windows and doors in a residential environment may affect a building’s natural ventilation rate, although the overall affect can range significantly depending on localized variables such as indoor/outdoor temperature differences, outdoor wind speeds, building orientation and opening size, etc. For example....

- Indoor to **outdoor temperature differences, opening size and duration, and outdoor wind effects and window geometry** (Jong and Bot, 1992), have been shown to directly affect the air exchange rate (AER) of a building (Wallace et al. 2002; Howard-Reed et al. 2002; Jordan 1963).
- Johnson (2004) measured a test house AER with **multiple openings** (windows and doors) and found the geometric mean to change from 0.76 h⁻¹ for no openings to 1.51 h⁻¹ for one opening, 2.30 h⁻¹ for two openings and 2.75 h⁻¹ for three or more openings.
- In 1945, Hartmann et al. showed an increase by a factor of four in the AER when **windows were opened** only a few centimetres in small apartment buildings.
- Howard-Reed et al. (2002) presented significant data of **window and door openings** in two buildings, demonstrating a maximum increase of greater than one air change per hour for the largest opening area between the houses and two to three air changes per hour for multiple window openings under a variety of different window opening combinations.
- Vatisstas et al (2007) found a significant effect of **indoor to outdoor temperature difference** on AER in a building where automatic doors cycled open and closed.

Research Goal

An **analysis of air exchange rates** in a research test house due to intentional:

- (1) window openings** and
- (2) door openings**

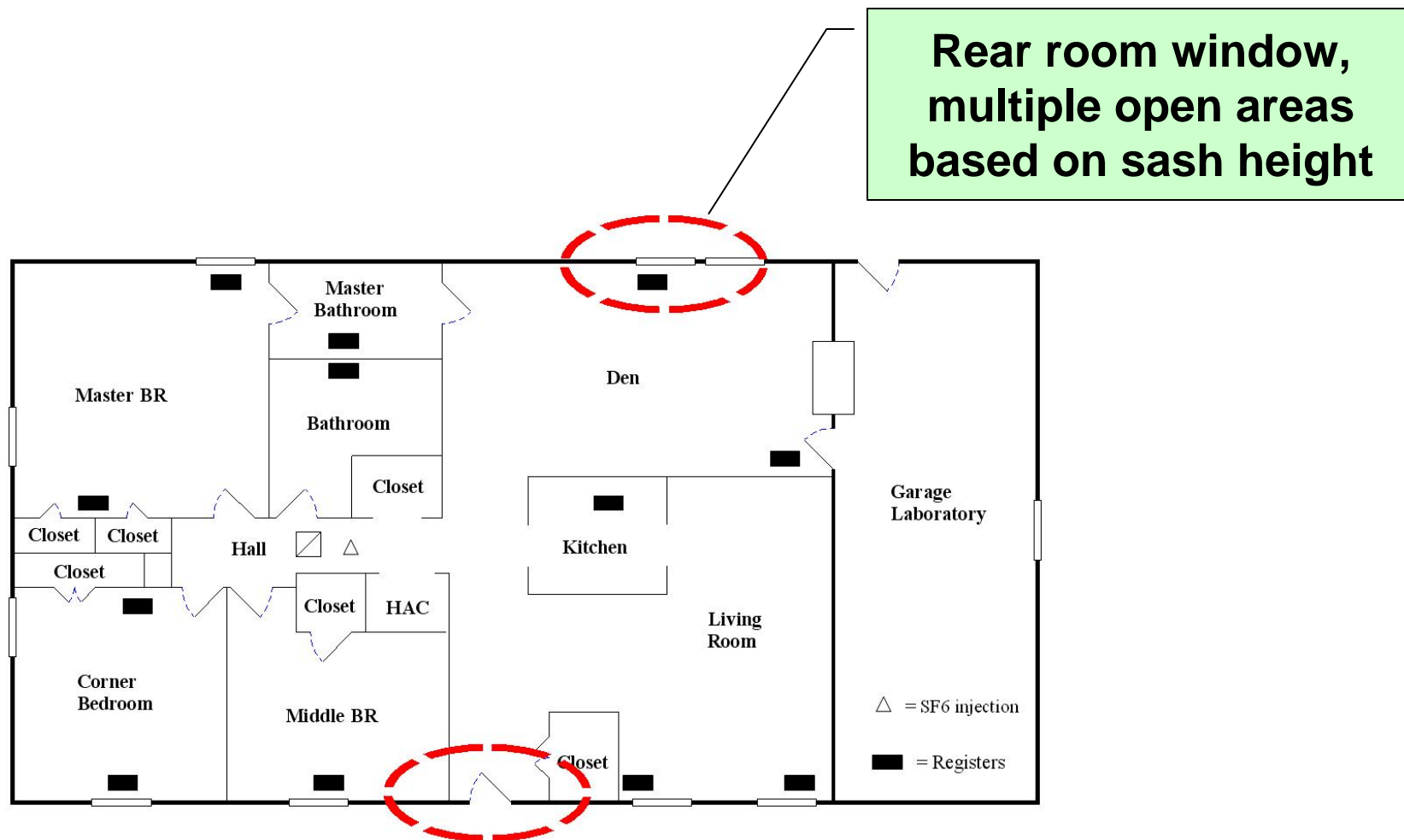
Setup

EPA Research test house

- Single story
- 1,300 square ft
- 10,333 cubic feet (292 m³)



Research Test House – Window Open Area



Methodology:

Open Window Scenario

Air Exchange rate

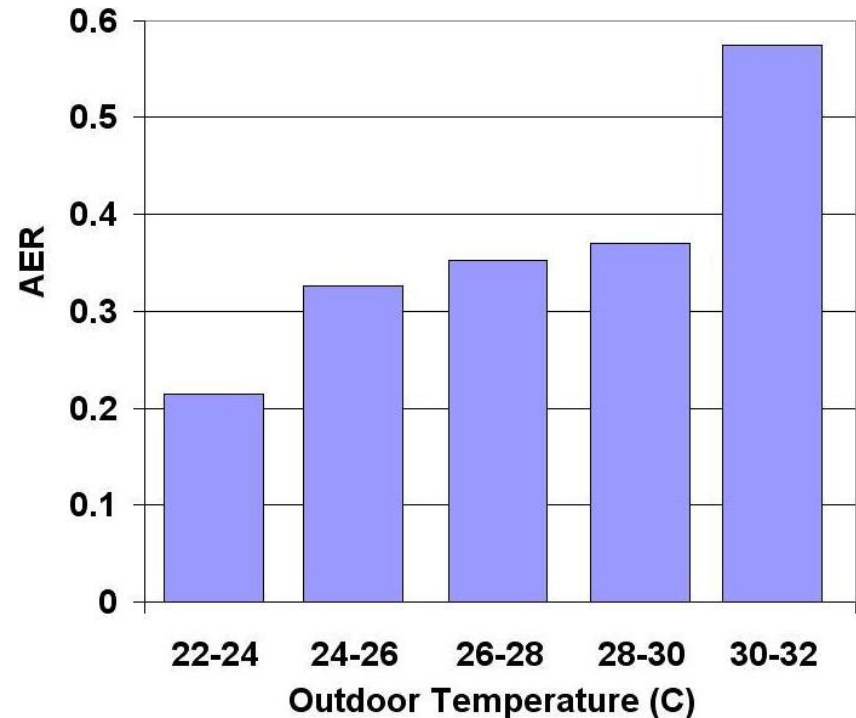
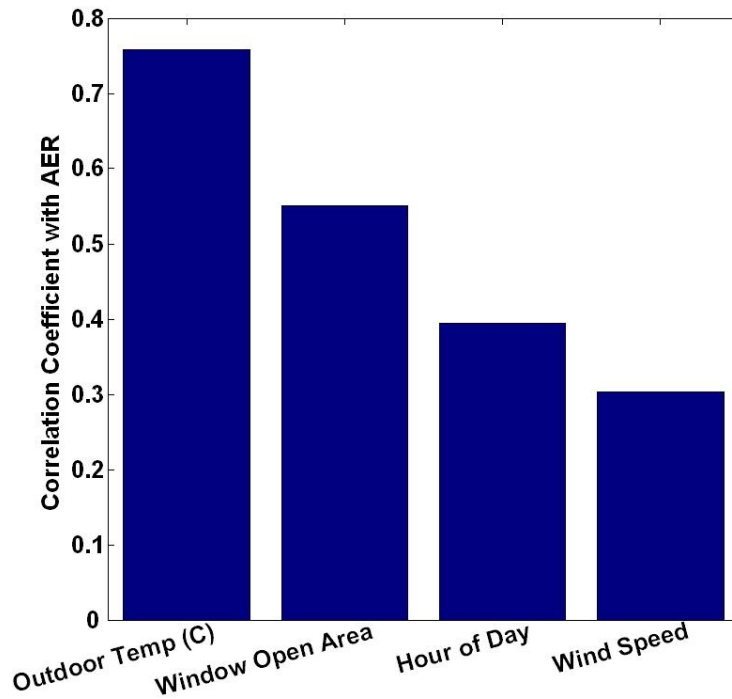
Air exchange rates were determined using tracer gas decay measurements. Injection of the tracer gas occurred every six hours, for a **total of 65 injection cycles**. Outdoor temperatures were measured using a local outdoor temperature sensor while indoor temperatures were maintained by the HAC system at 22 deg C (72 deg F). There is no mechanical ventilation capability.

Window Open Area

Five different window openings were used (width 89 cm, height 2.54, 5.08, 10.16, 20.32 and 40.64 cm, corresponding to 226, 452, 903, 1806 and 3613 cm² open areas respectively) and the closed window condition.

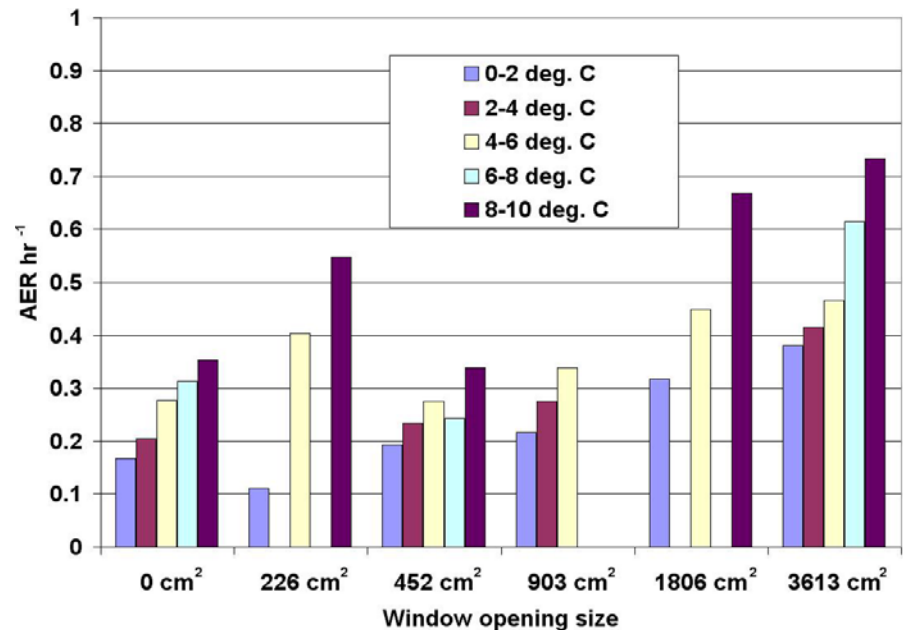
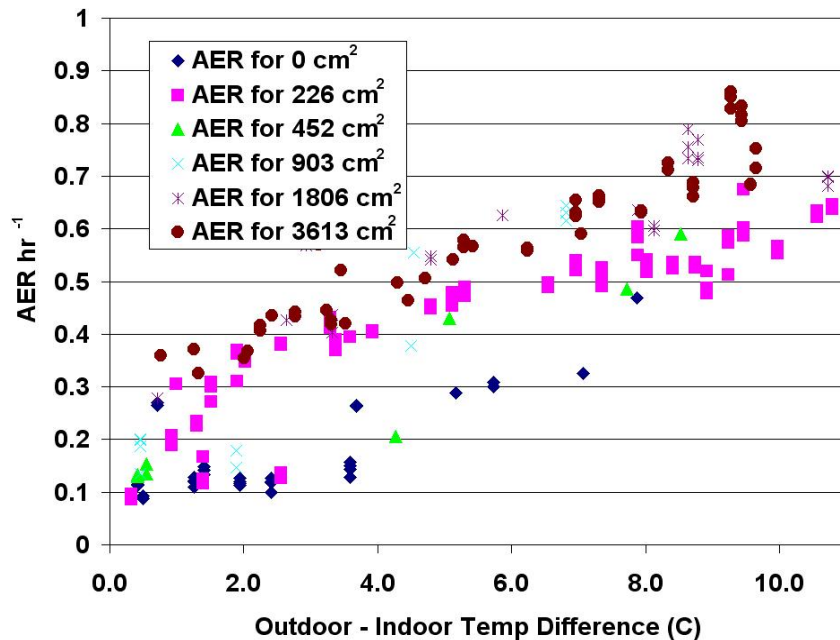
Results – Window Openings

$$r = \frac{1}{n-1} \sum_{i=1}^n \left(\frac{x_i - \bar{x}}{s_x} \right) \left(\frac{y_i - \bar{y}}{s_y} \right)$$



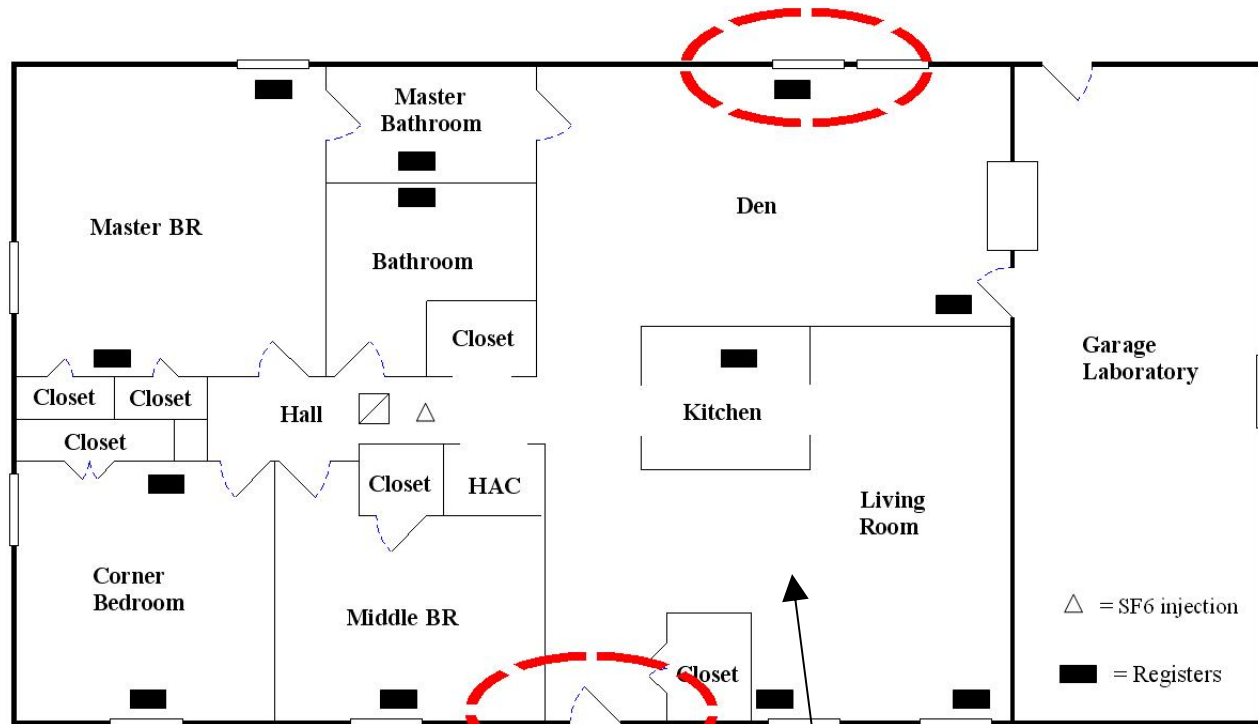
Correlation coefficient of measured variables with AER for all outdoor temperatures and window open areas (left image), for all outdoor temperatures over the HAC set point, including all window openings. On the right, AER (h-1) for specific outdoor temperature ranges including all window open areas.

Results – Window Openings



AER in each RTH room plotted against indoor to outdoor temperature difference for multiple window open areas (left image). Average AER for the master bedroom plotted against window open area for multiple indoor to outdoor temperature differences (right image).

Research Test House – Door Openings



Front door

**SF6 decay
measurement
location**

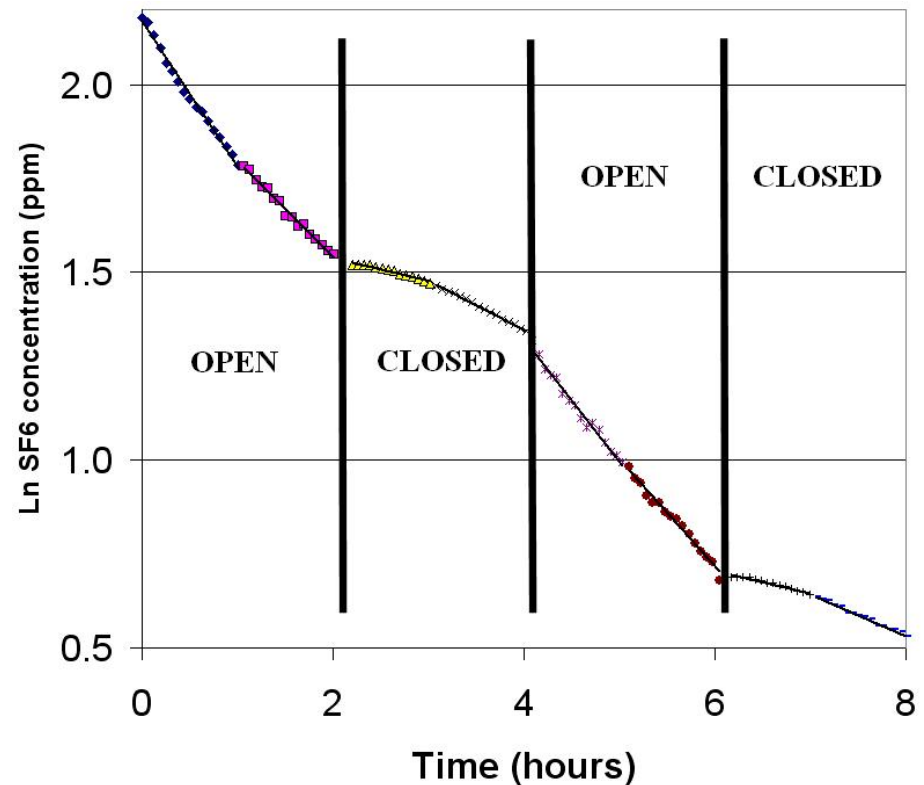
Methodology: Door Opening Scenario

Air Exchange Rate

Air exchange rates were determined using SF₆ decay measurements. Injection at HAC intake was followed by 30 minutes of HAC recirculation fan to increase mixing, followed by static conditions.

Door Opening Frequency

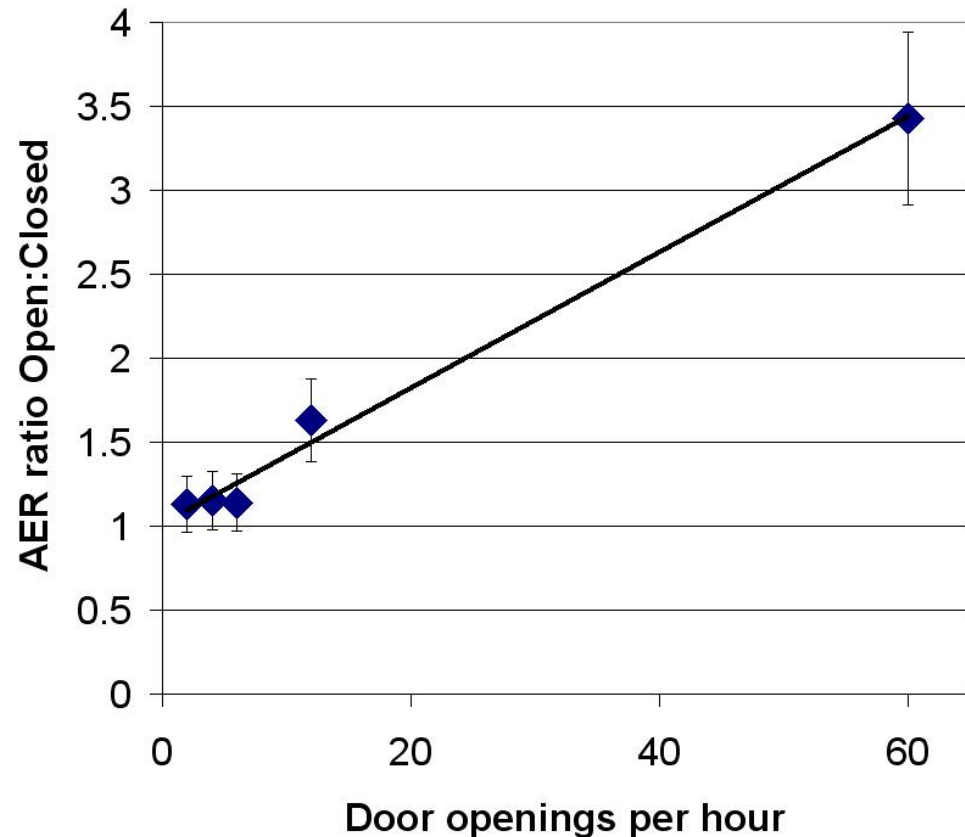
For each test, the door was opened for an average of 6.2 seconds, at a steady rate of 3, 4, 6, 12, and 60 openings per hour respectively in 2 hour on/off opening periods.



Example of indoor SF₆ concentrations during the door opening scenario.

Results – Door openings

An increase in the door opening frequency (x-axis) is directly related to the air exchange rate increase (y-axis)



Conclusions

Windows

- Data analysis shows a dependence of air exchange rate on door opening frequency and duration, window opened area and indoor to outdoor temperature differences.
- The increase in AER with increased indoor to outdoor temperature difference supports the existing findings that open windows used as a means of residential ventilation can increase energy costs due to HAC use when indoor to outdoor temperature differences increase (Hartmann et al. 1945).

Doors

- A measureable effect of door opening on the AER was not seen until the door open frequency was increased to 12 openings per hour. This door opening frequency is not often the case for the residential environment, but may be more prominent in population dense buildings such as high rise complexes.